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Study of Structural Behaviour of Gravity Dam with Various Features of Gallery by FEM

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Abstract **-The size and shape of opening in dam causes the stress concentration, it also causes the stress variation in the rest of the dam cross section. The gravity method of the analysis does not consider the size of opening and the elastic property of dam material. Thus the objective of study is comprises of the Finite Element Method which considers the size of opening, elastic property of material, and stress distribution because of geometric discontinuity in cross section of dam. Stress concentration inside the dam increases with the opening in dam which results in the failure of dam. Hence it is necessary to analyses large opening inside the dam. By making the percentage area of opening constant and varying size and shape of opening the analysis is carried out. For this purpose a section of Koyna Dam is considered. Dam is defined as a plane strain element in FEM, based on geometry and loading condition. Thus this available information specified our path of approach to carry out 2D plane strain analysis. The results obtained are then compared mutually to get most efficient way of providing large opening in the gravity dam.**

Keywords- **Openings in dam, Finite Element Method, geometric discontinuity, Koyna Dam, 2D plane strain analysis, Ansys'11.**

I. Introduction

It has been observed that large openings in the dam induce higher stresses in the vicinity of them. In some cases, these openings have contributed increase in stresses.

The variation of stress according to different shapes is much more. A system of openings is provided within the body of gravity dams to serve various purposes. The layout, size and shape of the openings are based on their requirements in dam. Openings develop zone of tensile stresses since concrete is not designed to take up any tension hence it become necessary to reanalyze the dam section with openings. In this project the effect of size variation and shape variation of large galleries on dam is studied. Finite element analysis of the dam with large opening is necessary to determine the general stress field, as large openings (area more than 1.5m x 2.25m) are not considered in the IS: 12966: 1990. Therefore, in this paper, analysis of concrete gravity dam for different shapes & sizes of openings is presented. The analysis is done using ANSYS'11 as analysis tool which based upon Finite Element Method.

II. System Development

Gravity dam is a solid plain strain structure. Its thickness is much greater than its other two dimensions, that's why it has been analyzed as 2D plain strain structure. Gravity dam is subjected to various forces like hydrostatic pressure, uplift pressure *etc*. due to which it causes stress concentration within its body. Such stress concentration leads to localized failure zones in the structure [2]. Though the stress concentration is to be localized can leads to drastic damage to important structure like dam. The dam structure failure is analyzed using tools like Finite Element Method & ANSYS.

A. Plain Strain Analysis Of Koyna Dam

Problems involving long bodies, whose geometry and loading do not vary significantly in longitudinal directions, are referred to as plain strain problems. For example, a long cylinder such as tunnel, culvert, buried pipe, a laterally loaded retaining wall, and a long gravity dam. It is assumed that displacement in 'z' direction (w) is equal to zero, and displacements in 'x' and 'y' directions (u and v) are the function of 'x' and 'y' but are independent of 'z' [1].

Figure 1 shows typical cross-section of dam. In this case also the displacement of base is restrained in X-direction. The element used in this case is plane 82(Plain strain 8 noded quadrilateral isoparametric element).The dam is discretized into small number of finite element(plane 82)which is shown in the figure 2.

- Crossectional Area of dam = 3588.97 sq.m.
- Weight of dam = 3588.97 × 24
  = 86135.4 kN
- Pressure acting on dam is as shown in figure 3.

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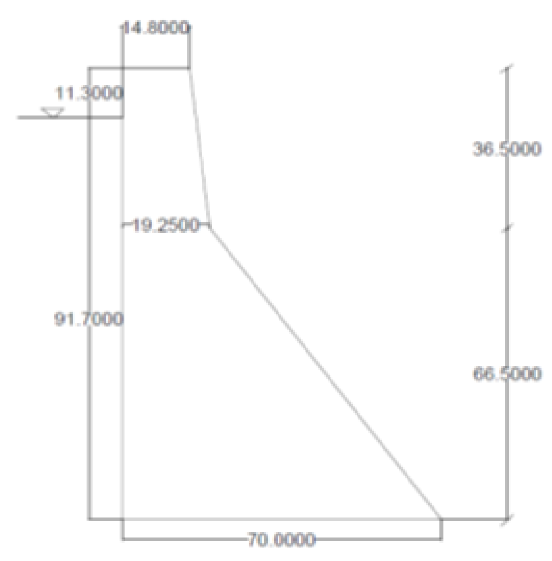


Figure 1.Typical cross-section of Koyna dam

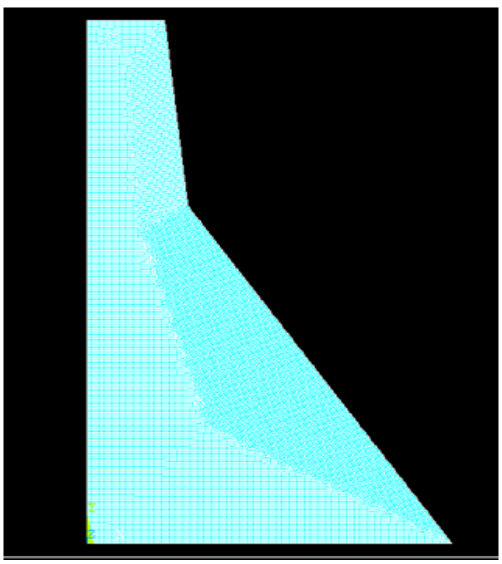


Figure 2.Meshing of cross section of Koyna dam

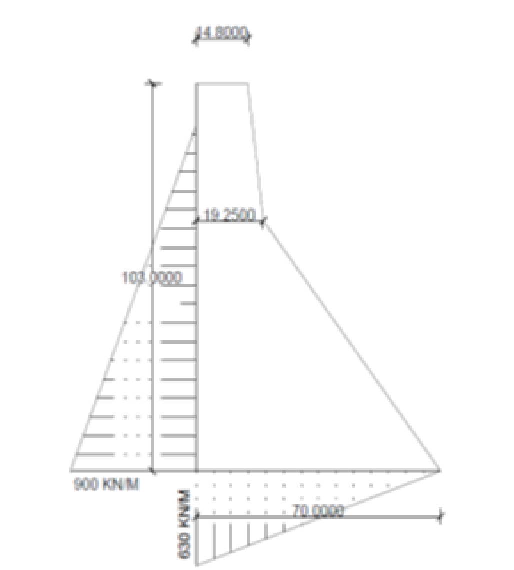


Figure 3.Pressure diagram of Koyna dam

By satisfying both checks of factor of Safety for overturning and sliding in static analysis of gravity dam, we can provide opening of approximately about 650sq.m. without disturbing its stability. This area is about 18.03% of cross sectional area of dam. But in the Ref [3], the maximum opening in the section of Khadakwasla dam is 7.53%. So we have provided gallery of maximum dimensions 4m. Thus, the size of opening is limited to 48 sq.m. i.e. 1.53% of the cross sectional area of dam. For the understanding the concept of analysis of opening in structure by FEM reference [4] [5] [6] [7] [8] [9] [10] [11] [12] [13] [14] are used and for loading and various checks for stability of dams IS Codes are used [15] [16] [17] [18].

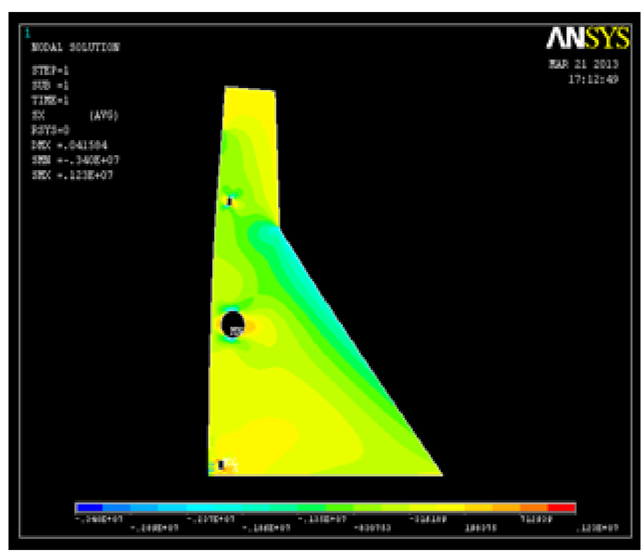
III. Computational Analysis

The computational analysis for finding out stress concentration around openings is carried out by using Ansys'11. The analysis is divided into 3 parts which are described below:

A. Analysis For Overall Effective Stresses Of Koyna Dam Using Ansys'11 For Different Cases

As per the aim of this paper, different shapes and sizes of galleries are taken in account for getting optimum results. The cases are described in appendix with three different location of galleries as shown in the figure 17. As tensile stress are critical in concrete gravity dam, so on the basis of minimum overall tensile stresses , critical case is described in Fig. 4 to Fig. 9 and Table 1and 2.

CASE 10



B. Analysis for Tensile Stress Around Opening of Koyna Dam in X- Direction

Up till now, study is only revolving around overall stresses, but in order to achieve the required aim of paper, the study further goes to tensile stresses around gallery in individual direction X and Y. So, on the basis of minimum tensile stress around opening in X direction, critical case is described in Fig. 10 and Fig. 11.

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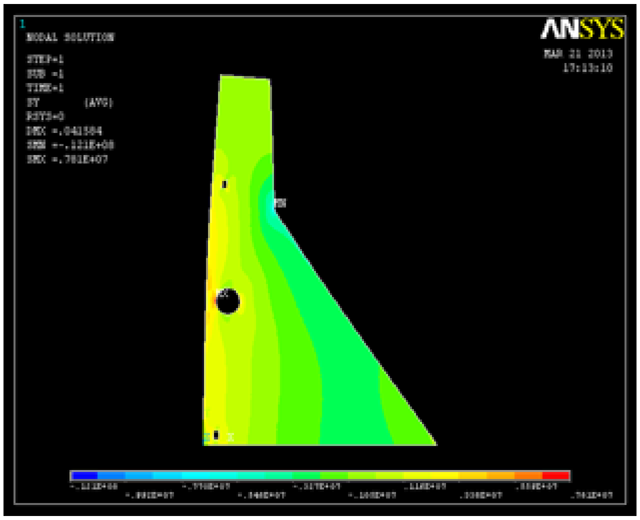


Figure 4.Normal Stress in x and y direction for Case 10

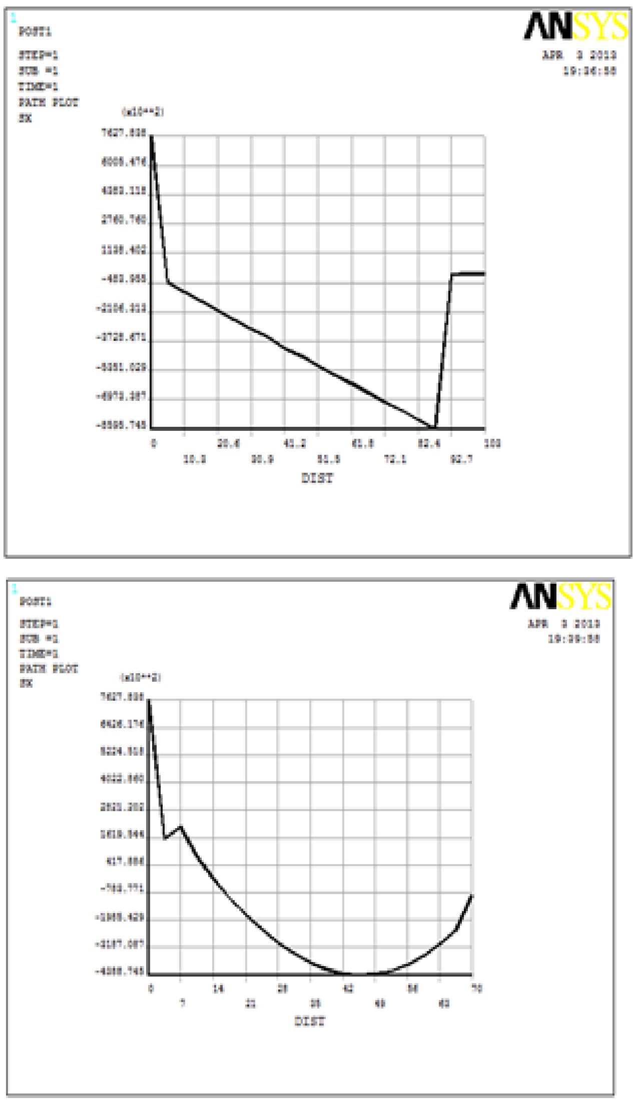


Figure 5.Stress Variation on Upstream Face and on base of Dam in x-direction for Case 10

The magnitude of maximum tensile stress around the second gallery for this case is 1820 kN/ m²

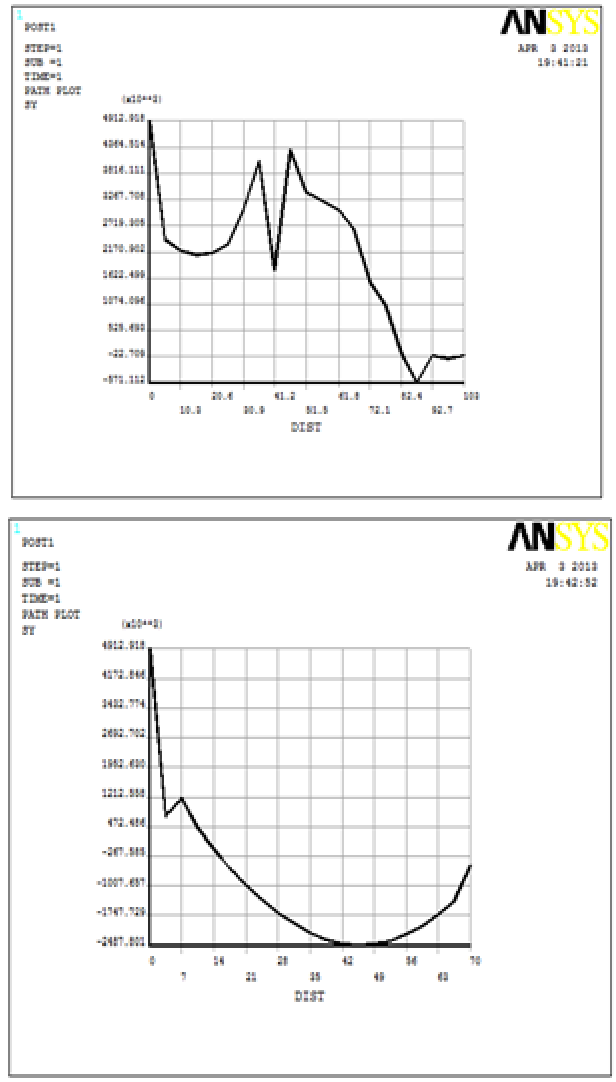
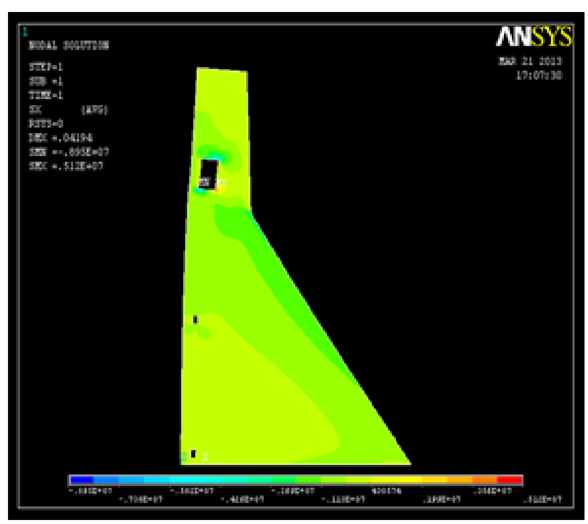


Figure 6.Stress Variation on Upstream Face and on base of Dam in y-direction for Case 10

TABLE I. STRESSES IN INDIVIDUAL DIRECTION AT TOE AND HEEL FOR CASE 10

Stress in X Direction (kN/ m^2)		Stress in Y Direction (kN/ m^2)	
At Heel	At Toe	At Heel	At Toe
762.7	78.3	491.2	435.0



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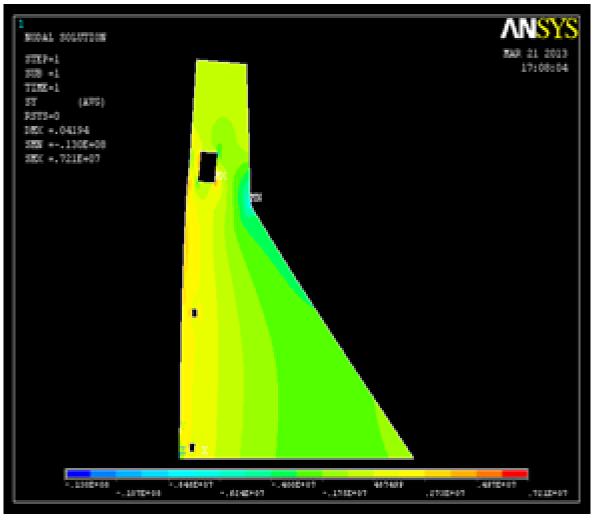


Figure 7. Normal Stress in x and y direction for Case 6

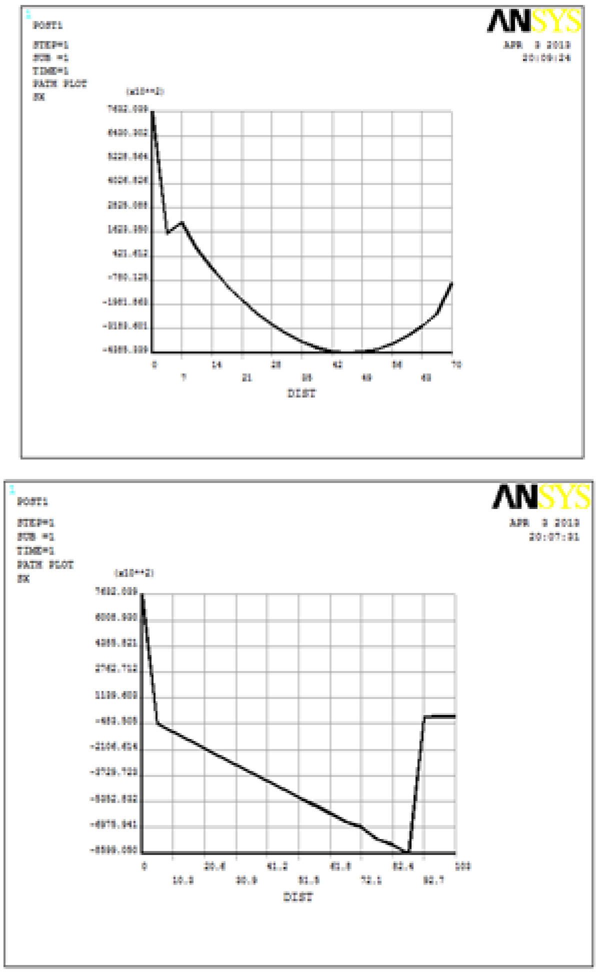


Figure 8. Stress Variation on Base and on Upstream Face of Dam in x-direction for Case 6

C. Analysis For Tensile Stress Around Opening of Koyna Dam In Y- Direction

In this article stress concentration around opening in Y-direction is considered. Rather than studying only one direction stress, this is better option to compare and give optimum gallery. So, on the basis of minimum tensile stress

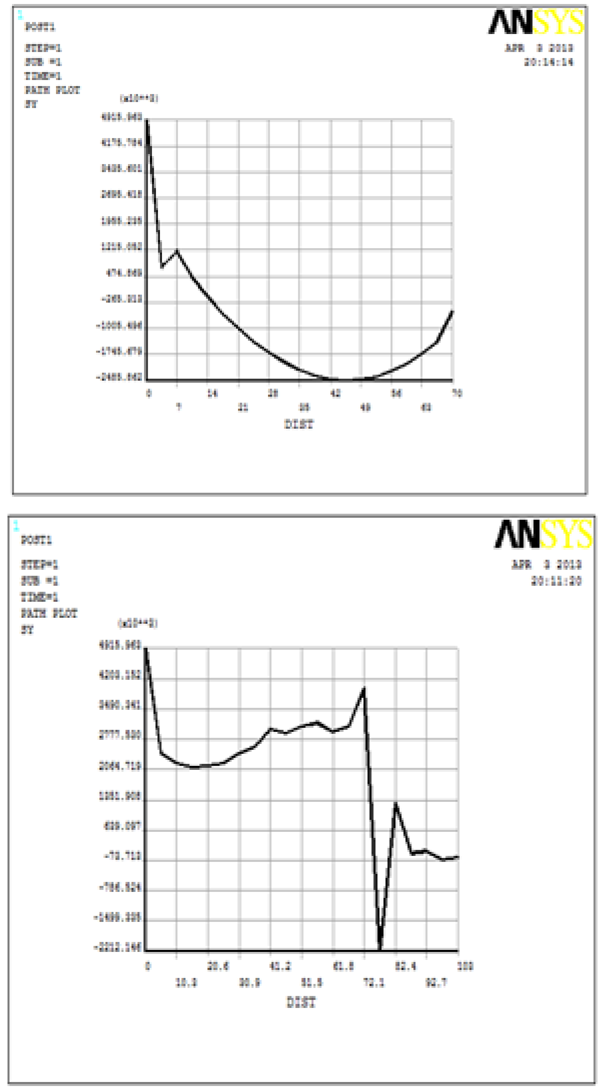
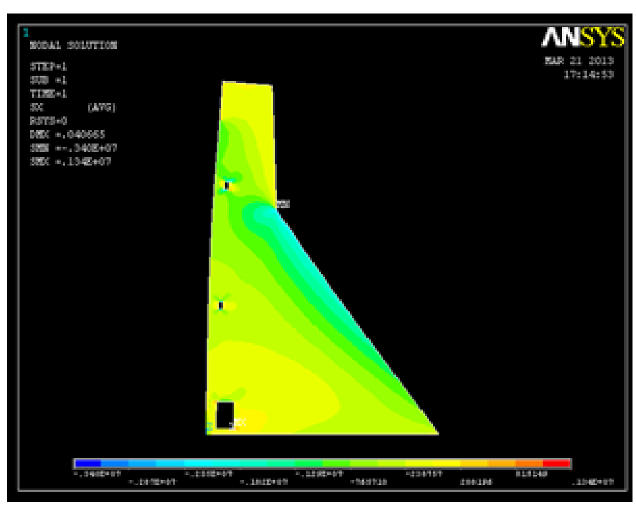


Figure 9. Stress Variation on Base of Dam and on Upstream Face in y-direction for Case 6

Table II. Stresses In Individual Direction At Toe And Heel For Case 6

Stress in X Direction (kN/ m^2)		Stress in Y Direction (kN/ m^2)	
At Heel	At Toe	At Heel	At Toe
763.2	48	4915	70

CASE 12



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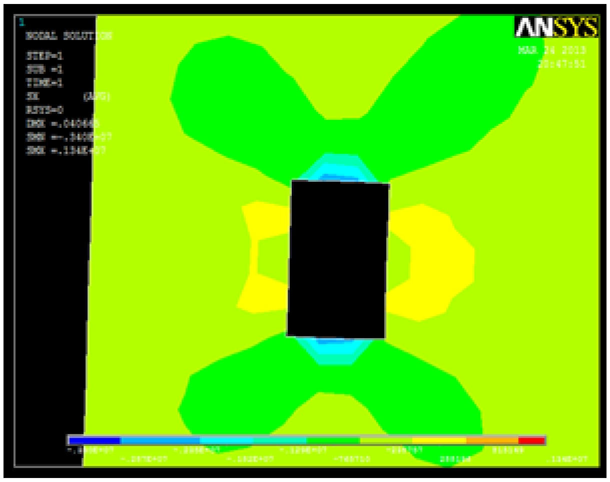

Figure 10. Normal Stress in x-direction for Case 12 and Close View of Second Gallery

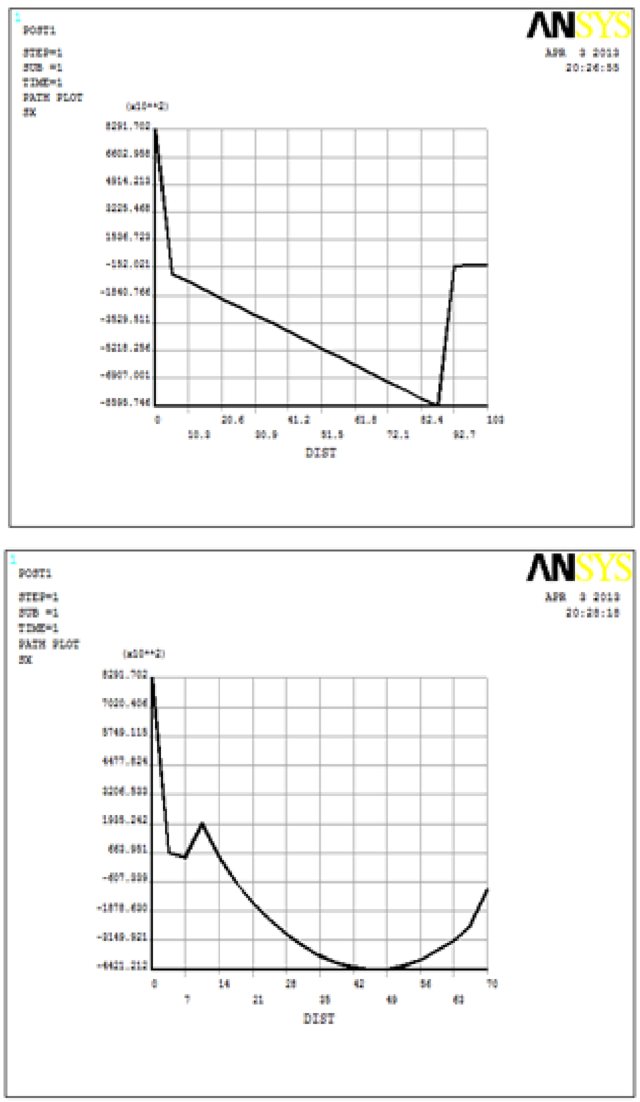

Figure 11. Stress Variation on Upstream Face and on base of Dam in x-direction for Case 12

around opening in Y direction, critical case is described in Fig. 12 and Fig. 13.

CASE 14

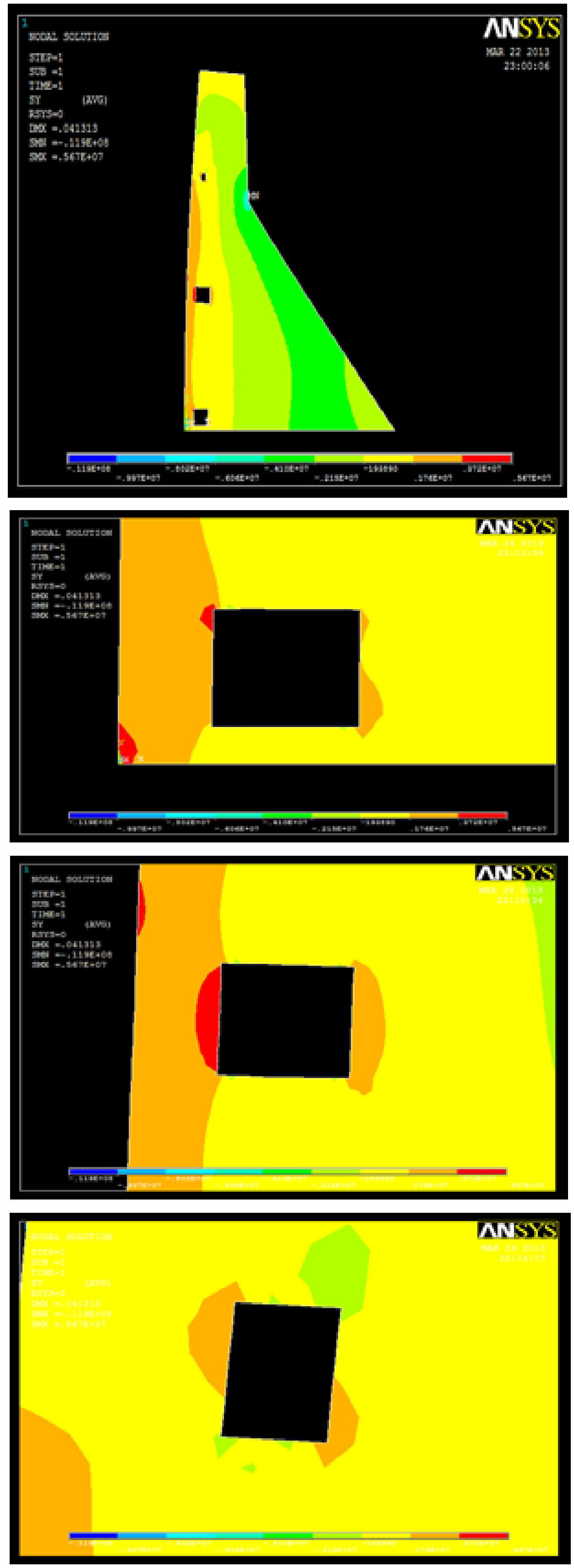

Figure 12.Normal Stress in y-direction for Case 14 and Close View of First, Second and Third Gallery respectively

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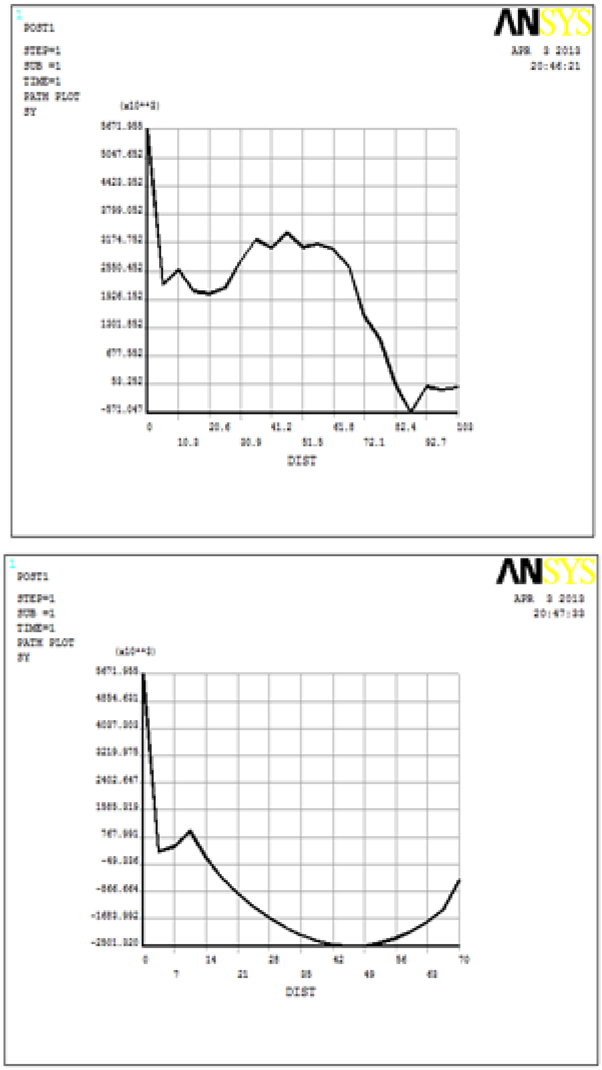

Figure 13. Stress Variation on Upstream Face and on base of Dam in y-direction for Case 14

Magnitude of average minimum tensile stress is 2150 kN/m^2 for all three galleries.

D. Optimum Results

Now comparing the optimum case from optimums of article A, article B and article C, the resultant stress contours and magnitude of overall compressive stress in body dam has been compared in this article. Thus from article A the case 10 is optimum, from article B case 12 is optimum and from article C case14 is optimum. Thus resultant stress contours of above 3 cases are shown in the Figures 14, 15 and 16.

From Table III, it is clear that resultant maximum compressive stress in all three cases are not much varying to suggest a single optimum. As they are optimum in their respective cases and also resultant stresses are compressive in all three cases.

Conclusions

1. Maximum overall tensile stresses in X-direction inside the dam, for optimum case (case 10) are less than 37% than worst case (case 6).

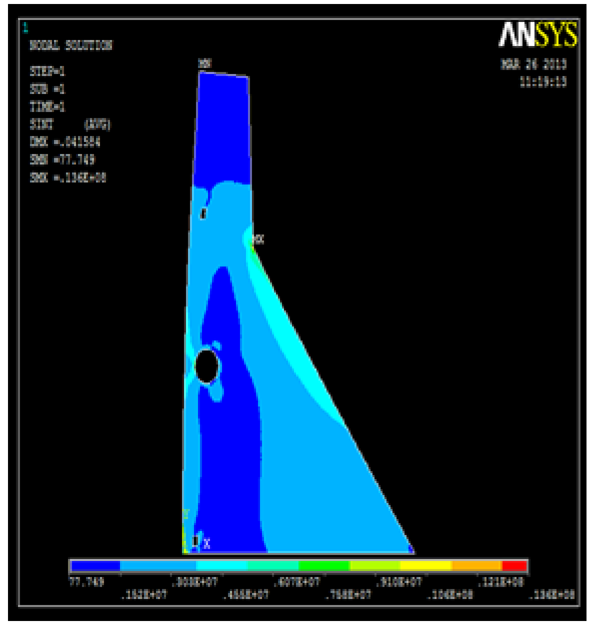

Figure 14.Resultant Compressive Stress in Dam (Case 10)

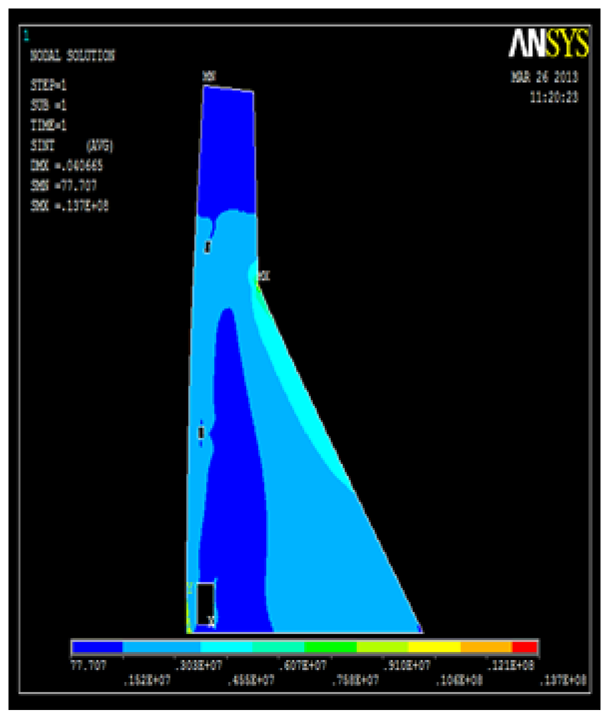

Figure 15.Resultant Compressive Stress in Dam (Case 12)

2. Maximum overall tensile stresses in Y-direction inside the dam, for optimum case (case 10) are less than 7% than worst case (case 6).

3. Maximum tensile stresses in X-direction around the gallery, for optimum case (case 12) are less than 42% than worst case (case 6).

4. Maximum tensile stresses in Y-direction inside the dam, for optimum case (case 14) are less than 20% than worst case (case 6).

5. Maximum compressive stress in the body of dam, for optimum case (from any of case 10, case 12, case 14) about 10% less than worst case (case 6).

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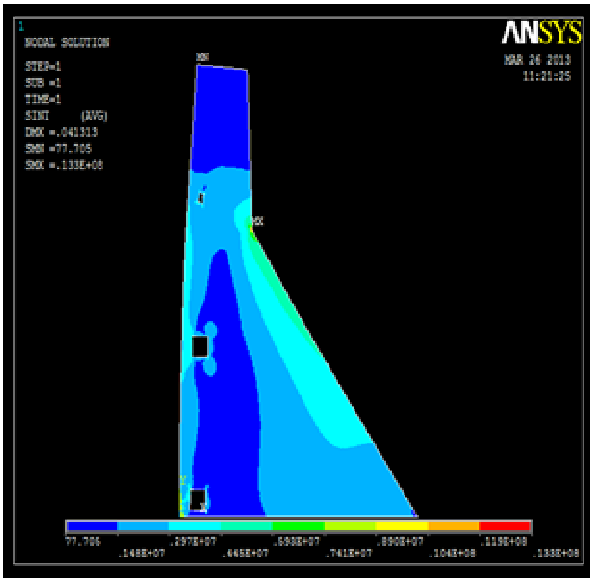

Figure 16.Resultant Compressive Stress in Dam (Case 14)

TABLE III. MAXIMUM COMPRESSIVE STRESS IN DAM FOR OPTIMUM THREE CASES

	Case 10	Case 12	Case 14
Maximum Compressive Stress (kN/m^2)	13600	13700	13300

Finally we conclude that case 14 (refer appendix) is the most efficient amongst the considered 22 cases with different types and location of galleries as shown in the Table IV. Also in case where tensile as well as compressive stresses exist in the dam it is better to provide rectangular shape of large opening.

From the presented study it has been observed that bottom and middle position gallery can be of large size (as in case 12 and case 14). Top position gallery must be of regular size.

APPENDIX A SHAPES, SIZE AND POSITIONS OF GALLERY IN CROSS SECTION OF DAM

Shapes and sizes of galleries used for different cases. Figure 17 shows the position of galleries in dam and table IV gives details about the sizes and shapes.

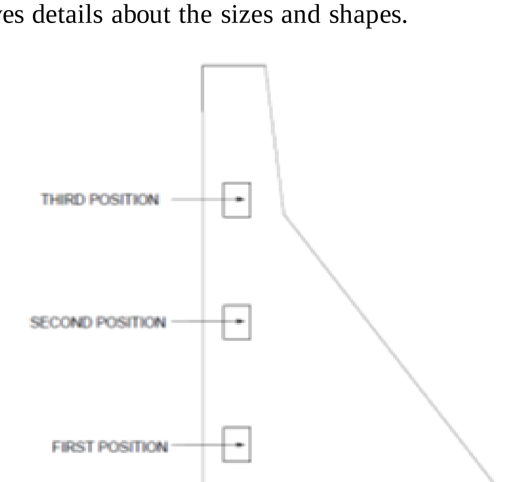

Figure 17. Positioning of gallery in cross-section of dam

TABLE IV. SHAPES AND SIZES OF OPENING FOR DIFFERENT POSITION

Sr. No.	Cases	Gallery 1	Gallery 2	Gallery 3
1	Case 1	Dam without opening		
2	Case 2	Square (4x4)	Square (4x4)	Square (4x4)
3	Case 3	Rectangular (3.26x4.89)	Rectangular (3.26x4.89)	Rectangular (3.26x4.89)
4	Case 4	Circular (Dia.- 4.51)	Circular (Dia.- 4.51)	Circular (Dia.- 4.51)
5	Case 5	Rectangular (1.5x2.25)	Rectangular (1.5x2.25)	Square (6.24x6.24)
6	Case 6	Rectangular (1.5x2.25)	Rectangular (1.5x2.25)	Rectangular (5.24x7.86)
7	Case 7	Rectangular (1.5x2.25)	Rectangular (1.5x2.25)	Circular (Dia.- 7.25)
8	Case 8	Rectangular (1.5x2.25)	Square (6.24x6.24)	Rectangular (1.5x2.25)
9	Case 9	Rectangular (1.5x2.25)	Rectangular (5.24x7.86)	Rectangular (1.5x2.25)
10	Case 10	Rectangular (1.5x2.25)	Circular (Dia.- 7.25)	Rectangular (1.5x2.25)
11	Case 11	Square (6.24x6.24)	Rectangular (1.5x2.25)	Rectangular (1.5x2.25)
12	Case 12	Rectangular (5.24x7.86)	Rectangular (1.5x2.25)	Rectangular (1.5x2.25)
13	Case 13	Circular (Dia.- 7.25)	Rectangular (1.5x2.25)	Rectangular (1.5x2.25)
14	Case 14	Square (4.72x4.72)	Square (4.72x4.72)	Rectangular (1.5x2.25)

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15	Case 15	Rectangular (3.86x5.79)	Rectangular (3.86x5.79)	Rectangular (1.5x2.25)
16	Case 16	Circular (Dia.- 5.33)	Circular (Dia.- 5.33)	Rectangular (1.5x2.25)
17	Case 17	Circular (Dia.- 5.33)	Rectangular (1.5x2.25)	Circular (Dia.- 5.33)
18	Case 18	Rectangular (3.86x5.79)	Rectangular (1.5x2.25)	Rectangular (3.86x5.79)
19	Case 19	Square (4.72x4.72)	Rectangular (1.5x2.25)	Square (4.72x4.72)
20	Case 20	Rectangular (1.5x2.25)	Square (4.72x4.72)	Square (4.72x4.72)
21	Case 21	Rectangular (1.5x2.25)	Rectangular (3.86x5.79)	Rectangular (3.86x5.79)
22	Case 22	Rectangular (1.5x2.25)	Circular (Dia.- 5.33)	Circular (Dia.- 5.33)

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